device that includes guard rings in the edge termination section is known. In the semiconductor device, the guard rings are connected electrically to the electrically conductive field plates connected in the forward and reverse voltage directions. Even if positive and negative charges exist on the edge termination section, the semiconductor device that includes the edge termination section as described above will weaken the adverse effects of the positive and negative charges on the depletion layer expansion in the vicinity of the device surface. As a result, the breakdown voltage is prevented from varying and the robustness against induced charges is improved.

[0013] Japanese Unexamined Patent Application Publication No. 2003-204065 (Paragraph 0038) describes a superjunction semiconductor device which includes, in the edge termination section, a field plate on an alternating-conductivity-type layer and a guard ring in the surface portion of the alternating-conductivity-type layer. Japanese Unexamined Patent Application Publication No. 2005-203565 (Paragraph 0013) describes a superjunction semiconductor device which includes a field plate on the alternating-conductivity-type layer in the edge termination section. The superjunction semiconductor device disclosed in these two documents exhibit a high breakdown voltage.

[0014] Japanese Unexamined Patent Application Publication No. 2003-224273 (Abstract) describes a first superjunction semiconductor device as described below. In the edge termination section around the first alternating-conductivity-type layer in the active section, the pitch and impurity concentrations in the second alternating-conductivity-type layer are set to be the same as the pitch and impurity concentrations in the first alternating-conductivity-type layer in the active section. Lightly doped p- and n-type regions are formed in the surface portions of the respective p- and n-type regions in the second alternating-conductivity-type layer in the edge termination section.

[0015] In a second superjunction semiconductor device disclosed in Japanese Unexamined Patent Application Publication No. 2003-224273, a third alternating-conductivity-type layer is formed on the second alternating-conductivity-type layer in the edge termination section. The direction of the alternating arrangement of the lightly doped p- and n-type regions in the third alternating-conductivity-type layer is perpendicular to the direction of the alternating arrangement of the p- and n-type regions in the second alternating-conductivity-type layer and heavily doped p-type regions are formed in the surface portion of the third alternating-conductivity-type layer.

[0016] Japanese Unexamined Patent Application Publication No. 2003-115589 (Abstract) describes a superjunction semiconductor device as described below. In the edge termination section around the first alternating-conductivity-type layer in the active section, the pitch and impurity concentrations in the second alternating-conductivity-type layer are set to be the same as the pitch and impurity concentrations in the first alternating-conductivity-type layer in the active section. A lightly doped n-type region is formed in the surface portion of the second alternating-conductivity-type layer and heavily doped p-type regions are formed in the surface portion of the lightly doped n-type region.

[0017] The structures described above relax the surface electric field in the edge termination section in the vicinity of the active section and hold a high breakdown voltage. Although the designed breakdown voltage is maintained initially, the breakdown voltage will lower gradually sometimes, if positive charges (positive ions) are induced on the edge termination section in the superjunction semiconductor devices disclosed in these latter two documents due to the reason described below.

[0018] Next, a device that includes a lightly doped alternating-conductivity-type layer arranged in the surface portion of the edge termination section is considered. Since a depletion layer expands easily in the surface of the alternating-conductivity-type layer and the electric field is relaxed, it is possible to obtain a higher breakdown voltage. However, as positively-charged ions are induced on the insulator film in the edge termination section, the depletion layer tends to hardly expand gradually, the electric field becomes higher around the field plate edge and the breakdown voltage lowers with passage of time. Therefore, it is considered that robustness against induced charges has not been taken yet.

[0019] Moreover, for holding the breakdown voltage characteristics, it is necessary for the superjunction semiconductor device disclosed in Japanese Unexamined Patent Application Publication No. 2003-115589 to form a uniform lightly-doped n-type surface region straddling the alternating-conductivity-type layer. Due to the additional steps for forming the n-type surface region, the manufacturing costs of the superjunction semiconductor device increase. It is necessary to dope the n-type surface region more lightly than the n-type drift region in the active section. However, it is difficult to controllably dope the n-type surface region more lightly than the n-type drift region in the active section.

[0020] In view of the foregoing, it would be desirable to solve the issues described above. It would be also desirable to provide a superjunction semiconductor device that facilitates manufacturing the edge termination section thereof exhibiting a high breakdown voltage and a high reliability for breakdown voltage through a process that exhibits a high mass-productivity. The present invention is directed to overcoming or at least reducing the effects of one or more of the problems set forth above.

SUMMARY OF THE INVENTION

[0021] According to an aspect of the invention, there is provided a semiconductor device including:

[0022] a heavily doped semiconductor substrate of a first conductivity type;

[0023] a first alternating-conductivity-type layer including a column-shaped or a layer-shaped first semiconductor region of the first conductivity type and a column-shaped or a layer-shaped second semiconductor region of a second conductivity type, the first and second semiconductor regions adjoining to each other repeatedly in parallel to the semiconductor substrate surface for forming a pn-junction therebetween, the pn-junctions extending in perpendicular to the semiconductor substrate surface;

[0024] the first alternating-conductivity-type layer working as a drift layer that makes a current flow in the ON-state of the semiconductor device and sustains a voltage in the OFF-state of the semiconductor device;

[0025] a surface structure on the surface side of the first alternating-conductivity-type layer, the surface structure constituting an active section that makes the current flow;

[0026] an edge-termination section surrounding the active section;

[0027] a second alternating-conductivity-type layer in the edge-termination section, the second alternating-conductivity-type layer including a column-shaped fourth semi-